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Improvement of Wave Loads Predictions by the 3D Time-Domain Computer Program SEALOADS

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Contract #W7707-008063/001/HAL

Contract Scientific Authority: Samon Ando Tele: 426-3100 Ext 203

Defence R&D Canada

Contractor Report
DREA CR 2001-191
November 2001

National Defence Défense nationale

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Abstract

Enhancement for the computer code SEALOADS version 1.0 was carried out and a new version 1.1 was produced. The mathematical model and the codes of SEALOADS version 1.0 were carefully examined for ways to improve the prediction of sea loads. A new algorithm has been developed to account for the effect of variable added-mass, damping and restoring coefficients on ship motions. A validation study for version 1.1 was conducted for the case of a frigate at the Froude number 0.12. Results were compared with those from PRECAL and SHIPMO7 as well as the experimental data. A total-factor-error analysis was also carried out using two wave spectra - ITTC and JONSWAP. The computed results show an improvement in the sea loads prediction.

Résumé

La version 1.0 du code machine SEALOADS a été perfectionnée pour donner la version 1.1. On a étudié le modèle mathématique et les codes de la version 1.0 du SEALOADS pour trouver des moyens de mieux prédire les charges de mer. Un nouvel algorithme a été créé pour tenir compte de l'effet des coefficients de masse ajoutée, d'amortissement du roulis et de rappel sur les mouvements des navires. Une étude de validation de la version 1.1 a été effectuée dans le cas d'une frégate au nombre de Froude égal à 0,2. Les résultats ont été comparés à ceux du PRECAL et du SHIPMO7 et aux données expérimentales. Une analyse des erreurs dues au total des facteurs a été également accomplie grâce à deux spectres de vagues – ITTC et JONSWAP. Les résultats calculés montrent une amélioration de la prédiction des charges de mer.

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Executive summary

Enhancement for the computer code SEALOADS version 1.0 was carried out and a new version 1.1 was produced. The mathematical model and the codes of SEALOADS version 1.0 were carefully examined for ways to improve the prediction of sea loads. A new algorithm has been developed to account for the effect of variable added-mass, damping and restoring coefficients on ship motions. A validation study for version 1.1 was conducted for the case of a frigate at the Froude number 0.12. Results were compared with those from PRECAL and SHIPMO7 as well as the experimental data. A total-factor-error analysis was also carried out using two wave spectra - ITTC and JONSWAP. The computed results show an improvement in the sea loads prediction.

The results show that the prediction of shear force and bending moment by SEALOADS version 1.1 has been improved. Compared with SEALOADS versions 1.0, the new version provides a more robust and practical means for calculating large-amplitude nonlinear loads that are beyond the realm of the conventional linear frequency-domain models.

The extreme loads are a key factor to be considered in the hull structural analysis, but because they occur very rarely, the characteristics of these loads are still poorly understood. SEALOADS serves as a practical analytical tool for examining them. Consideration of variable wetted surface and other enhancements of SEALOADS show promising improvements of wave loads prediction in extreme seas.

Future plans include further validation studies, refinement of the algorithms and/or theoretical models to improve the robustness, development of a more advanced method of calculating bow-flare impact force, application of the panel-free method for the computation of radiation and diffraction forces, and development of body-exact algorithm for large-amplitude motions. As well, development of a comprehensive analysis tool for the realistic hydroelastic response of the ship girder based on the framework of SEALOADS is envisaged.

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Sommaire

La version 1.0 du code machine SEALOADS a été perfectionnée pour donner la version 1.1. On a étudié le modèle mathématique et les codes de la version 1.0 du SEALOADS pour trouver des moyens de mieux prédire les charges de mer. Un nouvel algorithme a été créé pour tenir compte de l'effet des coefficients de masse ajoutée, d'amortissement du roulis et de rappel sur les mouvements des navires. Une étude de validation de la version 1.1 a été effectuée dans le cas d'une frégate au nombre de Froude égal à 0,2. Les résultats ont été comparés à ceux du PRECAL et du SHIPMO7 et aux données expérimentales. Une analyse des erreurs dues au total des facteurs a été également accomplie grâce à deux spectres de vagues – ITTC et JONSWAP. Les résultats calculés montrent une amélioration de la prédiction des charges de mer.

Les résultats montrent que la version 1.1 de SEALOADS améliore la prédiction de la force de cisaillement et des moments de flexion. Cette nouvelle version fournit des moyens plus robustes et plus pratiques par rapport à la version 1.0 quant au calcul des charges non linéaires à grande amplitude qui se distinguent des modèles classiques des domaines de fréquences linéaires.
Les charges extrêmes représentent un facteur essentiel à considérer lors de l'analyse des structures de la coque, mais comme elles se produisent très rarement, leurs caractéristiques sont encore très mal comprises. Le programme SEALOADS constitue un outil pratique pour les analyser. La prise en considération de la variation de la surface immergée, d'une part, et d'autres améliorations du SEALOADS, d'autre part, promettent manifestement des progrès dans la prédiction des charges de vagues dans des conditions maritimes extrêmes.

Les futurs plans prévoient des études de validation plus approfondies, une précision des algorithmes et/ou des modèles théoriques pour assurer la robustesse et le développement d'une meilleure méthode servant à calculer la force des chocs contre le dévers de l'étrave, l'application de la méthode sans panneaux qui sert à calculer les forces de radiation et de diffraction et le développement d'algorithmes précis du corps pour les mouvements à grande amplitude. On envisage également le développement d'un outil d'analyse complète pour le comportement hydroélastique du support du navire en fonction de la structure de SEALOADS.

Qui W., Peng H., and Hsiung C.C., 2001. Improvement of Wave Loads Prediction by the 3D Time Domain Computer Program SEALOADS. DREA CR 2001-191. Defence Research Establishment Atlantic.

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Chapter 1

Introduction

Over the past few years, a time-domain code, SEALOADS version 1.0, has been developed to predict nonlinear ship motion, hydrodynamic pressure distribution over the wetted surface, and sea loads. This work was done by the research group at the Center for Marine Vessel Development and Research (CMVDR), Dalhousie University, and sponsored by the Defence Research Establishment Atlantic (DREA). The research group continues to work on the improvement and further development of SEALOADS at Martec Limited.

The first and second phases of the SEALOADS project involved the theoretical development and numerical verification. In the third phase, the conclusions and recommendations from the second phase were implemented and a module for transient bow-impact loads was incorporated into the code. In the fourth phase, extensive validation was carried out using both the model-test data with a Canadian Patrol Frigate (CPF) model in regular and irregular waves and the theoretical responses of an M-Class container ship predicted by other time-domain codes.

In the current phase, the correlation studies of SEALOADS (version 1.0) based on the data from tests with the CPF model has been reviewed and analyzed. The mathematical model and the codes of SEALOADS were examined specifically to identify the ways to improve

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the prediction of sea loads. A new algorithm has been developed to account for the effect of variable added-mass, damping and restoring coefficients on ship motions. The enhanced version is called SEALOADS version 1.1. Theoretical Manual and User's Guide for this version were updated accordingly. A validation study for version 1.1 was carried out for the Halifax-Class frigate at Fn=0.12. Results were compared with those from PRECAL version 4 and SHIPMO version 7.1. A total-factor-error (TFE) analysis (Ando, 1998) was also conducted corresponding to two wave spectra - ITTC and JONSWAP (sea states 5 and 6).

The code enhancement of SEALOADS version 1.0 is outlined in Chapter 2. Chapter 3 presents the validation results. Conclusions and recommendations are given in Chapter 4.

Chapter 2

Enhancement of SEALOADS Version 1.0

The code of SEALOADS version 1.0 was reviewed and modified to improve the accuracy of sea loads prediction. The enhanced version is called SEALOADS version 1.1.

The changes to SEALOADS version 1.0 are summarized as follows:

- Tables of the Green function and its derivatives were extended.
- The computation of radiation and diffraction forces due to memory effect was enhanced.
- The sea loads module was examined and modified.
- Progress was made to compute sea loads on multiple cross-sections, instead of one cross-section (as in version 1.0) in each run.
- A hydrostatic component due to oscillatory ship motion has been added for pressure computation.
- Effects of variable hydrodynamic coefficients were incorporated into the code.

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- The theoretical manual and User's Guide were updated accordingly.

2.1 Code Modification and Enhancement

2.1.1 Green Function Tables

In the radiation and diffraction components of SEALOADS version 1.0, tables for the Green function and its derivatives were set up as functions of natural variables (β,μ), where $\beta = \sqrt{g/r_1}t$ and $\mu = -(z+z')/r_1$, r_1 is the distance between a field point (x, y, z) and the image of a source point (x', y', z') , g is the gravitational acceleration and t is the time (see Theoretical Manual for details). It was found that the upper limit of β, $\beta_{max} = 40.0$, is not big enough, particularly if there are small panels close to the waterline and the time t is large. This may cause the computed response functions for radiation and diffraction forces to be incorrect and consequently ship motions and sea loads to be inaccurate.

The program for generating Green function tables was therefore modified to extend β_{max} to 160.0. In general, this change will allow SEALOADS to accept arbitrary panels. However, extremely small panels should not be located near the waterline. New tables for the Green function and its derivatives are provided in version 1.1.

Extensions of the Green function tables also impact on the following modules within the radiation and diffraction components of SEALOADS:

- Radiation - code was changed in the subroutine **intpln()** of *greent.f*.
- Diffraction - code was modified in the subroutine **intpln()** of *greent.f*

2.1.2 Radiation and diffraction forces due to memory effect

In SEALOADS version 1.0, the response functions for forces, sea loads and pressures in both radiation and diffraction components were computed at large time steps (**dt0**), and then they were interpolated at smaller time steps (variable denoted as **step**) for use in the kernel program. The maximum ratio for **dt0/step** was 20. This ratio was increased to 50. The code for interpolation of response functions was removed from radiation and diffraction components. A new program, *kij.f*, was added to the kernel module to perform this operation. The response functions with the time step, **dt0**, will be read in and interpolated at time steps, **step**. These enhancements provide users with more flexibility to change the time step without running radiation and diffraction modules which are time-consuming. These changes impact the following modules:

- Radiation - code was changed in the subroutine **output_kij_f()** and **output_kij_p()** of *inputnew.f*.
- Diffraction - code was changed in the subroutine **output_ki7_f()** and **output_ki7_p()** of *inputnew.f*.
- Kernel program - code was changed in the subroutine **Input_response_function()** of *input.f*.
- Kernel program - new subroutines, **kij_interpolation()**, **kijpre_interpolation()**, **ki7_interpolation()**, **ki7pre_interpolation()**, **Interpolate_Responsef()**, **fkij_interpolate()**, **fki7_interpolate()**, were added in the file, *kij.f*.
- Kernel program - code was also modified in subroutines for the computation of forces, pressures and sea loads as in files, *force.f*, *seaload.f* and *pressure.f*.

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2.1.3 Sea Loads Module

The sea loads module was completely reviewed and modified. Changes that were made to this modules are summarized below:

- The normal vector, *unxc*, was corrected in the file, *geometry.f*. This affected the computation of sea loads.
- To reduce the numerical errors, the computation of sea loads on cross-sections abaft the center of gravity was changed to start from FP instead of AP as in version 1.0. Consequently, subroutines **seaload_inertia()**, **seaload_rad()**, **seaload_dif()**, **seaload_raddif_convolution()** in *seaload.f* were changed.

2.1.4 Computation of sea loads on multiple cross-sections

In SEALOADS version 1.0, it was possible to compute sea loads only on one cross-section in each run. In version 1.1, this limitation was removed. Sea loads on a **maximum** of **20** cross-sections can now be computed at one time. The input and output formats were updated correspondingly. Due to this enhancement, the following subroutines were modified:

- Radiation - *rad.f* and **output_kij_f()** in *output.f*.
- Diffraction - *dif.f* and **output_ki7_f()** in *output.f*.
- Kernel program - *main.f* and **input_response_function()** in *input.f*, *output_seaload()* in *output.f* and most subroutines in *seaload.f*.

As shown in User's Guide, the corresponding input/output formats were changed as follows:

- Changes to <filename>.ctr

In SEALOADS version 1.0, an example of input for sea loads on the midship section is as follows:

The cross-section for sea loads computation
&xsection
xcx=0.0
/end{xsection}

In version 1.1, the format is given below:

Cross-sections for sea loads computation
&xsection
numxcx=2
xcx=0.0,-12.5
/end{xsection}

In this record, *numxcx* is the number of cross-sections for sea loads computation and *xcx* is an vector containing locations of cross-sections.

- Changes to output format, corresponding to cross-sections for sea loads computation, are straightforward, and are given in the file *<filename>.fx* as follows.

  In SEALOADS version 1.0, the format is

t(1)	fx(1,1)	fx(2,1)	...	fx(6,1)
t(2)	fx(1,2)	fx(2,2)	...	fx(6,2)
...	...	...	...	...
t(n)	fx(1,n)	fx(2,n)	...	fx(6,n)

  In version 1.1, the new format is given below:

t(1)	fx(1,1)	...	fx(6,1)	...	fx(1,1)	...	fx(6,1)
t(2)	fx(1,2)	...	fx(6,2)	...	fx(1,2)	...	fx(6,2)
...	...	...	...	...	...	...	...
t(n)	fx(1,n)	...	fx(6,n)	...	fx(1,n)	...	fx(6,n)
	cross-section 1				cross-section n		

2.1.5 Changes to Pressure Computation

A hydrostatic component due to oscillatory ship motion is added for pressure computation. The pressure at a point (x, y, z) on the wetted hull can then be written as

$$p(x, y, z; t) = p_R(x, y, z; t) + p_D(x, y, z; t) + p_I(x, y, z; t) + \delta p_s(x, y, z; t) \qquad (2.1)$$

where $p_I(x, y, z; t)$ and $p_D(x, y, z; t)$ are the pressures due to the incident waves and the diffracted waves, respectively, and $\delta p_s(x, y, z; t)$ is the hydrostatic pressure fluctuation due to the oscillatory ship motion. A subroutine, **motion_pressure()**, was added in the file of *pressure.f* in the kernel program.

Additionally, a module for pressure interpolation was added into the kernel program so that pressures at specific points can be output directly after running the kernel program. A new file, *presinterp.f*, was created and an additional input file, **<filename>.presxyz** is required for the pressure interpolation. Furthermore, users have options to output pressures on centroids of panels and/or specific points. Changes to input/output format are reflected in User's Guide (Qiu *et al.*, 2001).

2.2 Effect of Variable Hydrodynamic Coefficients

The instantaneous wetted surface changes drastically when a ship travels in large waves. The computation of radiation and diffraction forces in SEALOADS version 1.0 are linearized about the mean wetted surface, which remains time invariant. To extend the version 1.0 code to large waves and steep waves (nonlinear situation), a pseudo-nonlinear model is proposed, where the variable added-mass, damping and restoring coefficients are considered when computing the radiation and diffraction forces. A review of work on variability of hydrodynamic coefficient is presented in the Theoretical Manual for SEALOADS version 1.1 (Qiu *et al.*, 2001)

A position-dependent matrix is set up to consider various attitudes of ship including roll, pitch, heave and their combinations. The matrix for the CPF is given in Figure 2.1 based on maximum amplitudes of heave, roll and pitch from the experimental data, where heave is in meters and roll and pitch are in degrees. A compromise between the size of matrix and the computing time was made

The hydrodynamic coefficients are pre-computed corresponding to each of these attitudes. When solving equations of ship motion, the instantaneous hydrodynamic coefficients are linearly interpolated from the pre-computed table based on the computed roll, pitch and heave at the previous time step.

To discretize the hull surface corresponding to 125 attitudes in the matrix, an automatic panel generator based on Non-Unform Rational B-Spline (NURBS) surfaces was developed. The algorithm for this generator is included in the Theoretical Manual for SEALOADS version 1.1. Examples of panelized CPF hull with respect to various attitudes are also given in the Theoretical Manual.

The wetted surface is not symmetric about the center plane if the ship is heeled. Thus, the code for computation of hydrodynamic coefficients had to be modified to deal with asymmetric bodies. A new program was developed to compute the variable hydrodynamic

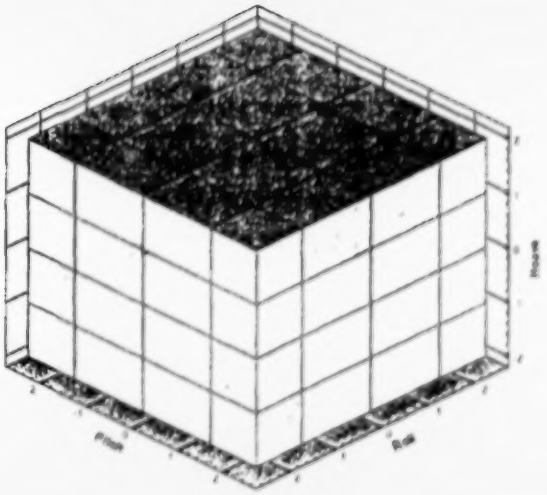

Figure 2.1: The position-dependent matrix for CPF

coefficients for 125 attitudes for CPF. Since there are two options to compute m-terms, two databases of variable hydrodynamic coefficients for CPF were produced: **cpfvadms.db** for simplified m-terms and **cpfvadmsf.db** for full m-terms.

Figures 2.2, 2.3 and 2.4 show the position-dependent heave and pitch added-mass, and pitch damping coefficients for the CPF, respectively for the case of simplified m-terms. In these figures, μ_{33} and μ_{55} are heave and pitch added-masses, ∇ is the volume displacement and λ_{55} is the pitch damping coefficient. The unit for heave is meter and roll and pitch are both in degrees. As shown, the heave added-mass is sensitive to roll motion. The pitch added-mass and damping coefficient are sensitive to both pitch and roll motions. These pre-computed hydrodynamic coefficients were used for interpolation in ship motion computations.

As an example in Figure 2.5, the roll motions were computed for CPF in oblique waves

(β = 135°) by using modules with and without consideration of variable hydrodynamic coefficients for CPF. As shown, the prediction of roll was improved by considering variable hydrodynamic coefficients.

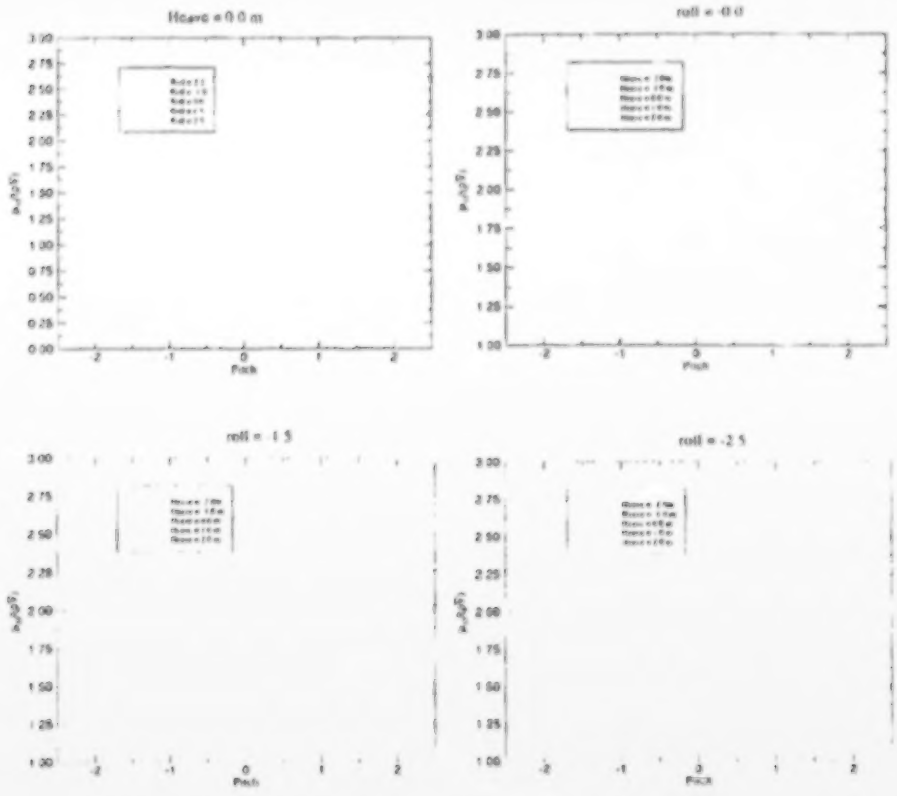

Figure 2.2 Variable heave added-mass

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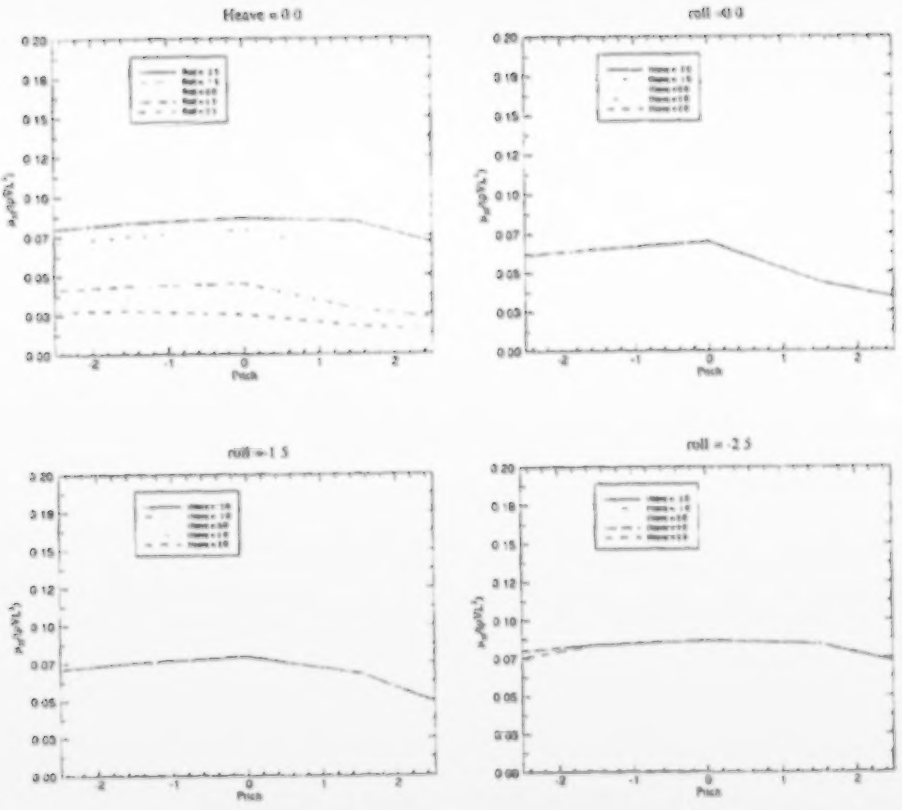

Figure 2.3: Variable pitch added-mass

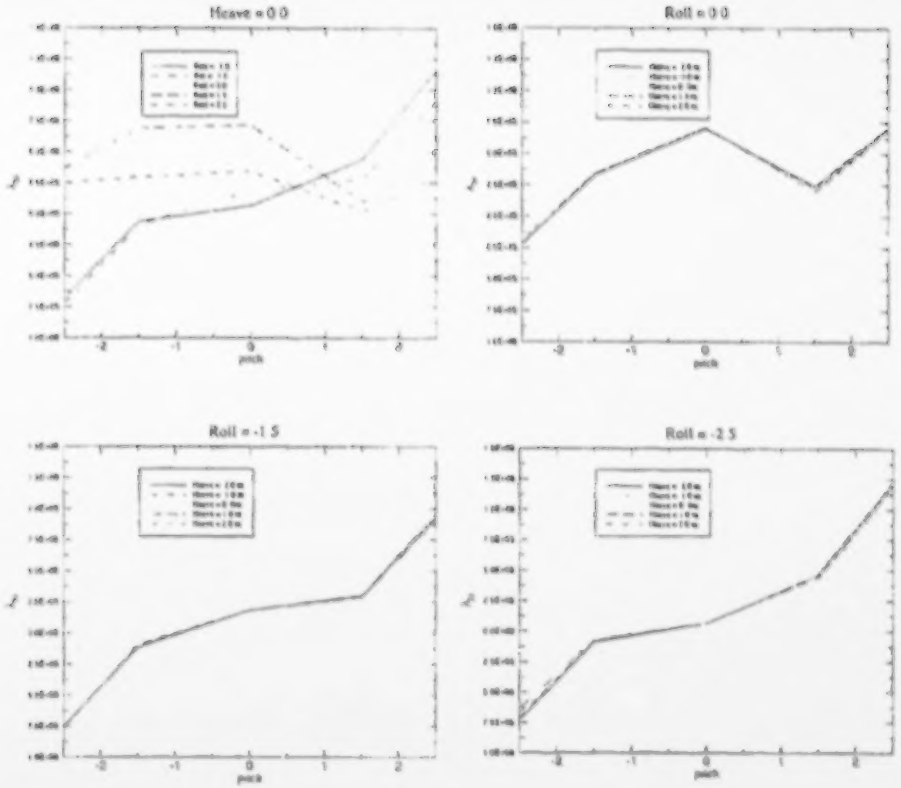

Figure 2 4: Variable pitch damping coefficients

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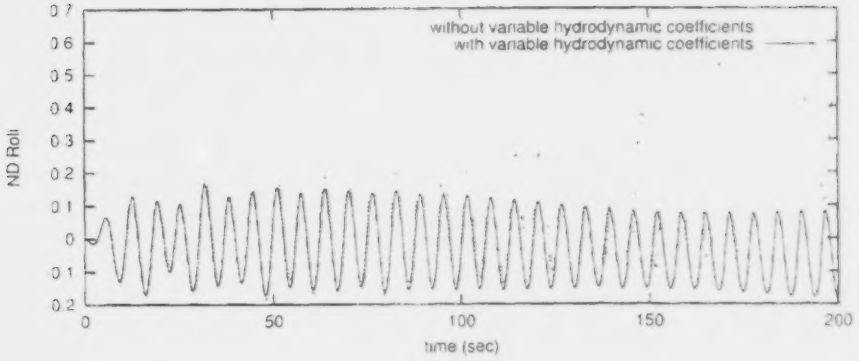

Figure 2.5: Effect of variable hydrodynamic coefficients on roll motion

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Chapter 3

Computed Results by SEALOADS Version 1.1

The enhanced SEALOADS version 1.1 was applied to the CPF for various cases at Fn=0.12 for which the model test results are available. The validation matrix is given in Table 3.1. The incident waves corresponding to H/λ=1/50, H/λ=1/30 and H/λ=1/20 are listed in Table 3.2. The hydrodynamic pressures were computed at sensors 4, 5, 6, 7, 8, 9 and 10, whose locations are given in Table 3.3 and also shown in Figure 3.1. Sea loads on stations 5, 10 and 13.7 were computed for cases of H/λ=1/30 and 1/20 in head seas and oblique waves.

Table 3.1: Summary of the validation matrix

Fn	Ship Speed (knot)	β (deg.)	H/λ
0.12	8.2	180	1/50, 1/30, 1/20
0.12	8.2	165	1/30, 1/20
0.12	8.2	135	1/30, 1/20

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Table 3.2: Regular waves in head and oblique seas

λ/L	$\omega(rad/s)$	ξ_a (m)		
		H/λ=1/50	H/λ=1/30	H/λ=1/20
0.59	0.92	0.735	1.224	1.836
0.70	0.84	0.872	1.453	2.179
0.80	0.79	0.996	1.660	2.490
0.89	0.75	1.108	1.847	2.770
1.01	0.70	1.257	2.096	3.144
1.09	0.67	1.357	2.262	3.393
1.19	0.64	1.482	2.469	3.704
1.36	0.60	1.693	2.822	4.233
1.57	0.56	1.955	3.258	4.887
1.94	0.51	2.415	4.026	6.038

3.1 Nondimensionalization

The amplitudes of ship motions are non-dimensionalized as

$$\bar{x}_i = x_i/\xi_a, \quad i = 1, 2, 3 \tag{3.1}$$

$$\bar{x}_i = x_i/(k\xi_a), \quad i = 4, 5, 6 \tag{3.2}$$

where $x_i, i = 1, 2, 3$ are amplitudes of surge, sway and heave,respectively; $x_i, i =, 4, 5, 6$ are amplitudes of roll, pitch and yaw, respectively; k is the wave number, and ξ_a is the amplitude of incident wave.

The non-dimensional shear forces and bending/torsional moments are defined as

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Table 3.3: Location of pressure sensors (in full scale)*

Sensor No.	Station	Distance from CL (m)	Height above BL (m)	x (m)	y(m)	z(m)
1	1.0	4.6	11.5	56.025	4.6	6.53
2	1.0	3.3	9.70	56.025	3.3	4.73
3	1.0	2.0	7.0	56.025	2.0	2.03
4	1.0	0.7	3.0	56.025	0.7	-1.97
5	1.0	0.0	0.0	56.025	0.0	-4.97
6	3.0	0.0	0.0	43.575	0.0	-4.97
7	3.8	0.0	-1.75**	38.595	0.0	-3.22
8	7.2	0.0	0.0	17.430	0.0	-4.97
9	9.5	0.0	0.0	3.1125	0.0	-4.97
10	13.0	0.0	0.0	-18.675	0.0	-4.97

* coordinates of sensor locations are described in the ship-fixed coordinate system

** sonar dome bottom

$$\bar{F}_i = F_i/(\rho g L_{pp} B \xi_a), \quad i = 1, 2, 3 \tag{3.3}$$

$$\bar{F}_i = F_i/(\rho g L_{pp}^2 B \xi_a), \quad i = 4, 5, 6 \tag{3.4}$$

where $F_i, i = 1, 2, 3$ are the axial force, the horizontal and vertical shear forces on a cross-section considered. $F_i, i = 4, 5, 6$ are the torsional moment, vertical and horizontal bending moments. L_{pp} and B are the length between perpendiculars and ship's beam, respectively; ρ is the water density; and g is the gravitational acceleration.

The non-dimensional hydrodynamic pressure is defined as

$$\bar{p} = p/(\rho g \xi_a) \tag{3.5}$$

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The computed motions, pressures and sea loads are compared with model test results. The computed results were also compared with those from SEALOADS version 1.0, PRECAL and SHIPMO7.

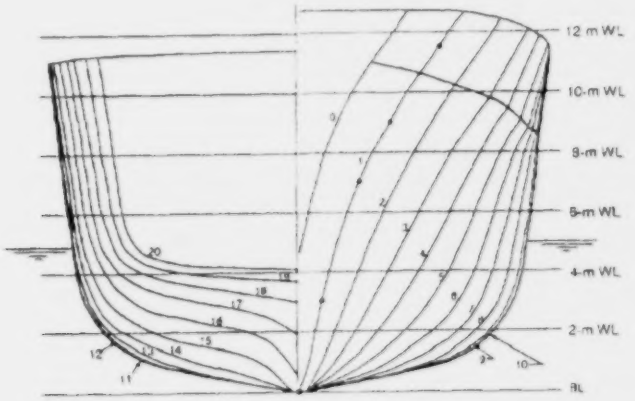

Figure 3.1 The body plan of CPF

The computed motions, sea loads and pressures at selected frequencies for $\beta = 180°$ are shown in Figures 3.2 to 3.9. The predicted sea loads by SEALOADS version 1.1 agree better with the experimental data than those by version 1.0. However, at the higher frequency side, sea loads are under-predicted. It is found there is a shift in mean response to a non-zero value, especially for heave motion. This indicates that the ship is not balanced. It might be the reason for the under-prediction of sea loads. It is anticipated that a module for hydrostatic balancing will be incorporated into SEALOADS. Predicted motions and sea loads for oblique seas ($\beta = 165°$ and $135°$) by version 1.1 are compared with those by version 1.0, SHIPMO7 and PRECAL, as well as experimental data in Figures 3.10 to 3.15. It is shown that the prediction of sea loads was improved.

To quantify the comparison, the total-factor-error (TFE) analysis was conducted. TFE's of heave, pitch, sea loads and pressures, for cases of $H/\lambda = 1/30$ and $\beta = 180°$, $135°$ and $165°$,

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are given in Tables 3.4 to 3.7 using the ITTC and JONSWAP spectra for the significant wave heights 3.25m and 5.0m, and the modal wave periods of 9.7s and 12.4s, respectively. The significant wave heights and modal wave periods correspond to sea states 5 and 6 (SS5 and SS6). In these tables, $(F_3')_x$ and $(F_5')_x$ represent the nondimensional vertical shear force and bending moment at station x, and $(p')_x$ denotes the nondimensional pressure at sensor x. As shown, prediction of pressures by SEALOADS version 1.1 is better than that by PRECAL at sensors #5, #9 and #10 in head seas. The extremely large TFE's of pressures at sensor #8 for both SEALOADS and PRECAL might indicate the inaccurate measurement. The predicted roll motions by SEALOADS version 1.1 are better than both PRECAL and SHIPMO7.

TFE's of predicted motions and sea loads on the midship section by SEALOADS version 1.0 were also computed for cases of $\beta = 180°$ and $\beta = 165°$. It can be seen in Tables 3.4, 3.5 and 3.6 that TFE's of predicted sea loads on the midship section by SEALOADS version 1.1 are significantly smaller than those for SEALOADS version 1.0. This also indicates the improvement of sea loads predictions.

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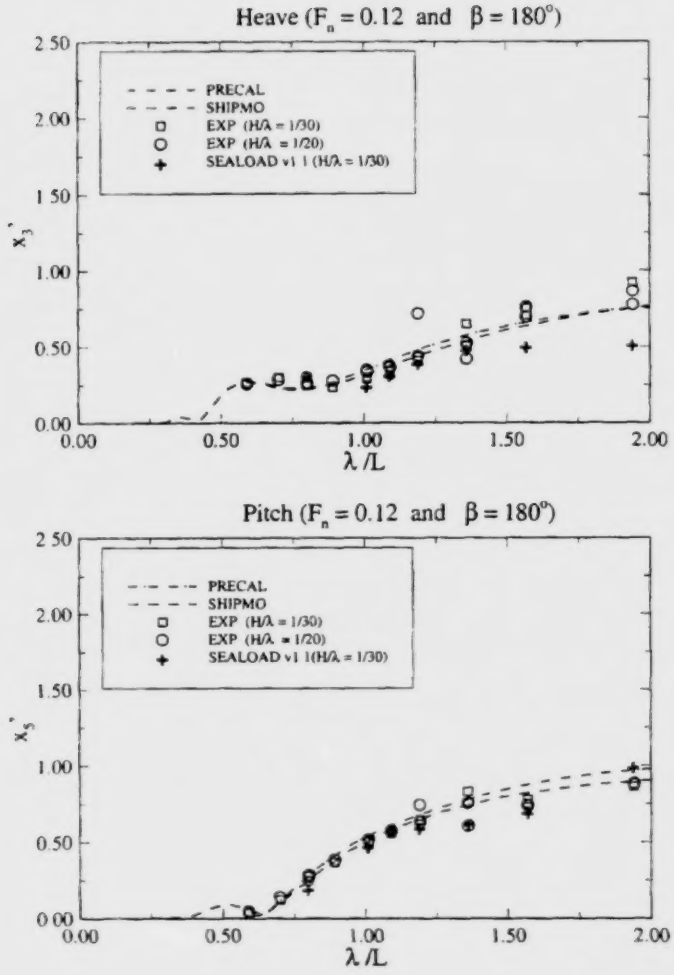

Figure 3.2: Predicted motions $\beta = 180°$, Fn=0.12

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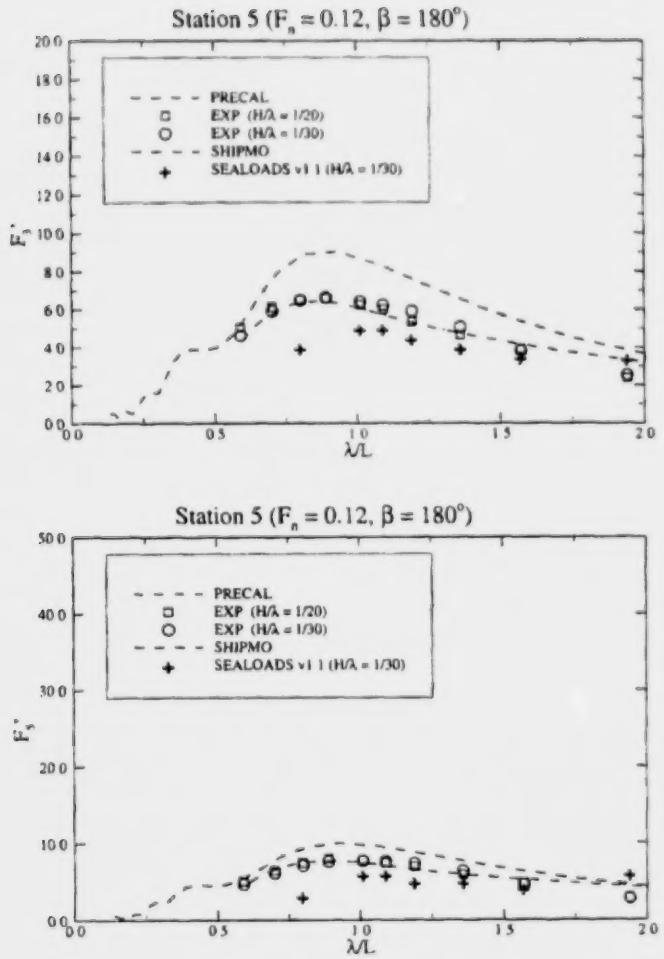

Figure 3.3: Predicted sea loads on station 5, $\beta = 180°$, Fn=0.12

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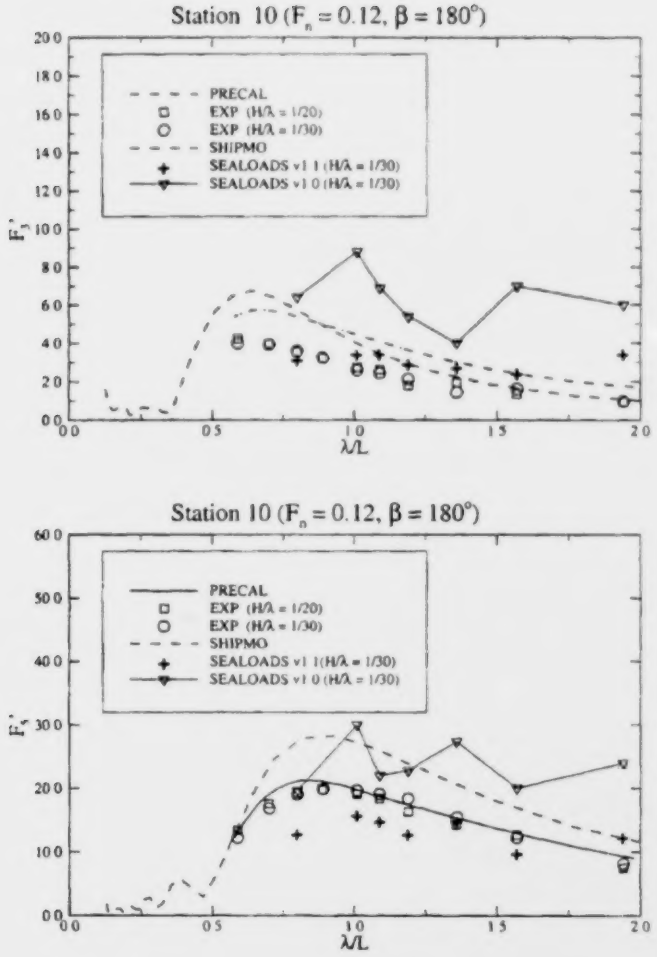

Figure 3.4: Predicted sea loads on station 10, $\beta = 180°$, Fn=0.12

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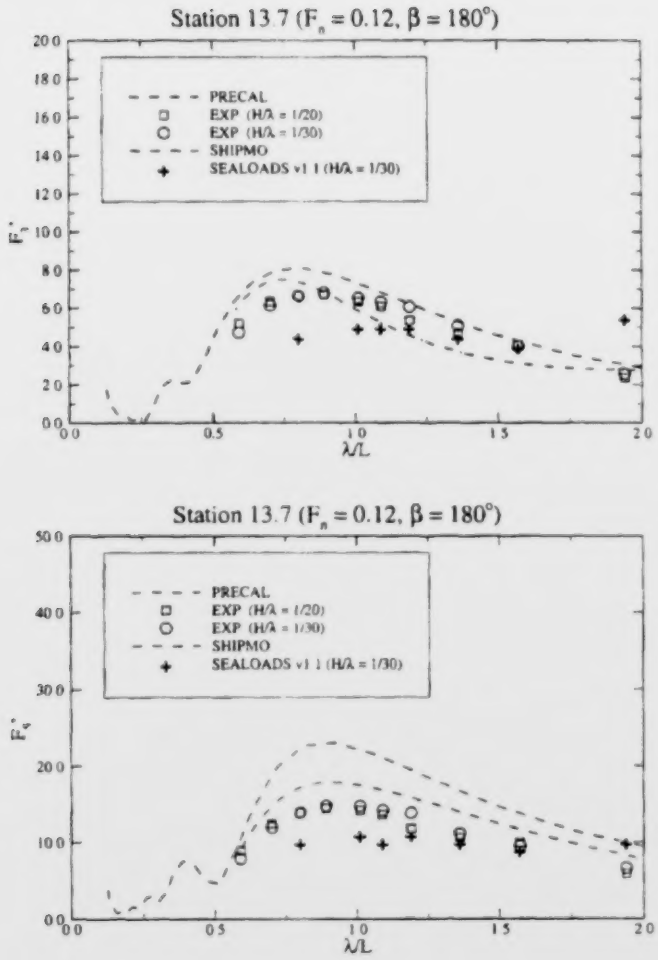

Figure 3.5: Predicted sea loads on station 13.7, $\beta = 180°$, Fn=0.12

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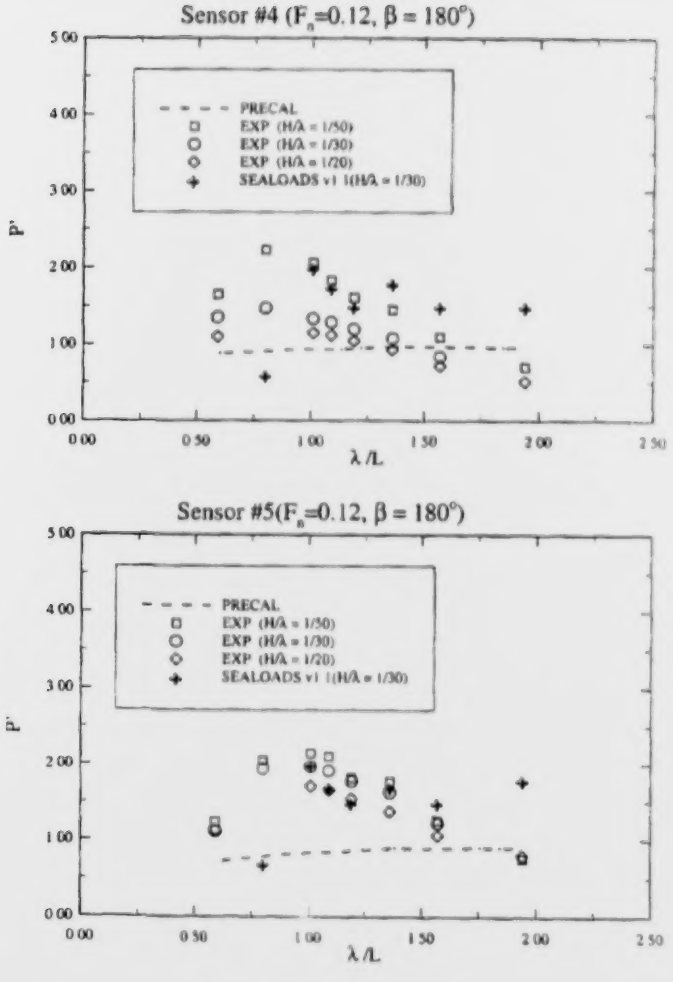

Figure 3.6: Predicted pressures on sensors 4 and 5, $\beta = 180°$, Fn=0.12

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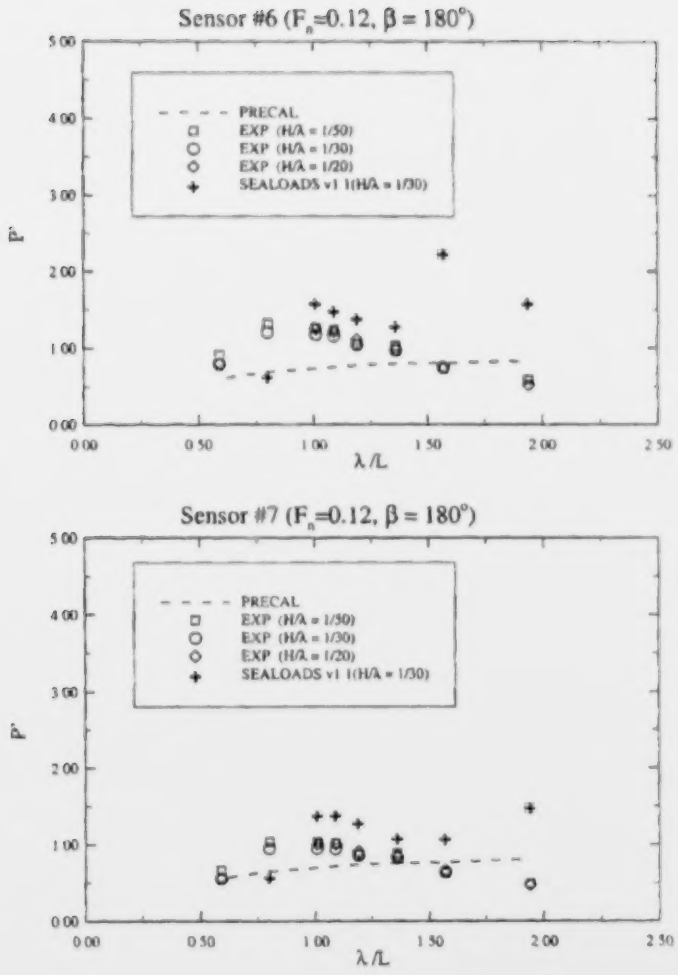

Figure 3.7: Predicted pressures on sensors 6 and 7, $\beta = 180°$, Fn=0.12

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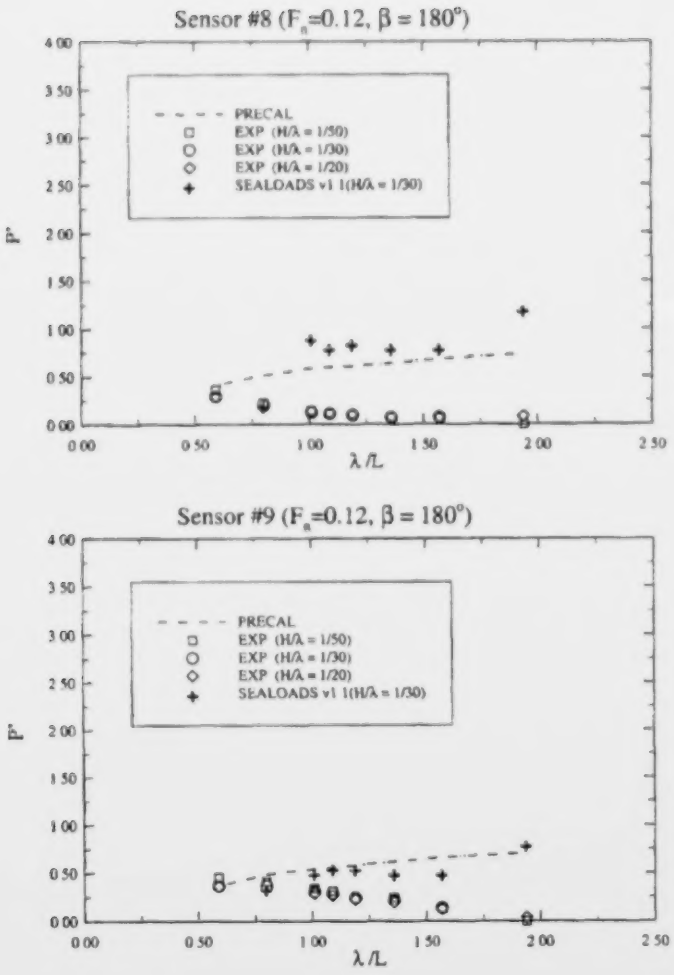

Figure 3.8: Predicted pressures on sensors 8 and 9, $\beta = 180°$, Fn=0.12

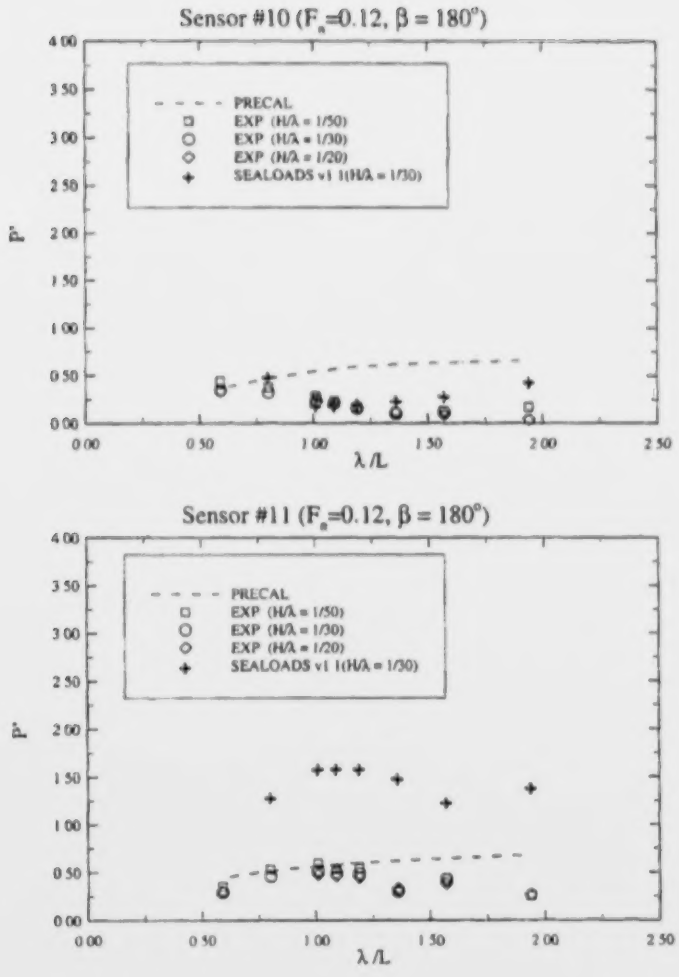

Figure 3.9: Predicted pressures on sensors 10 and 11, $\beta = 180°$, Fn=0.12

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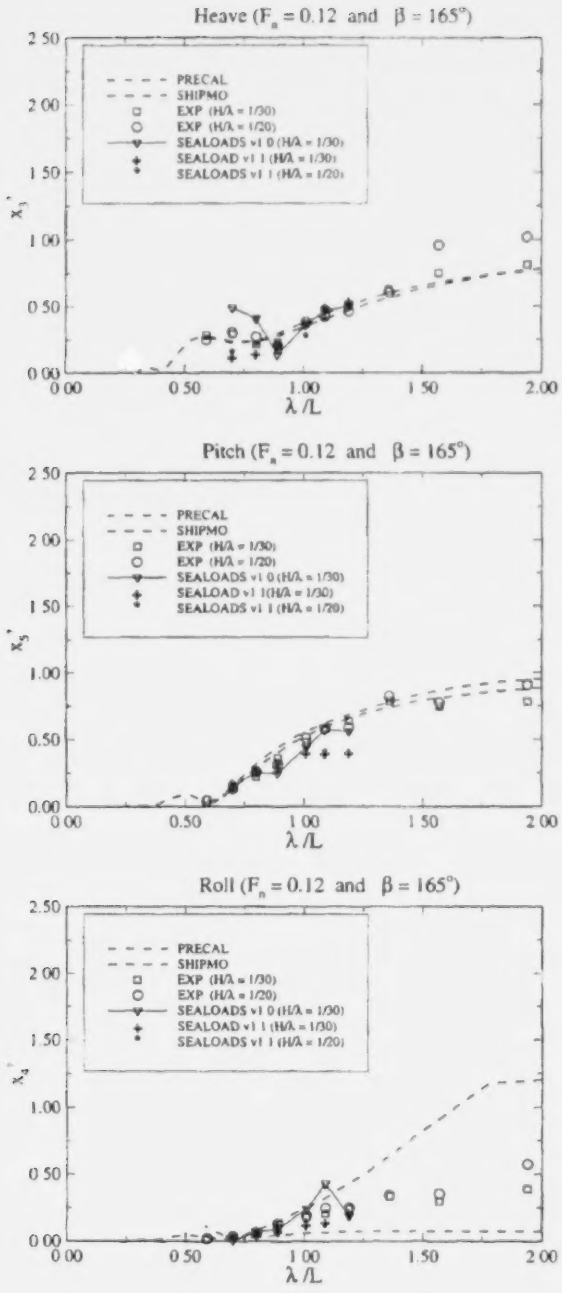

Figure 3.10: Predicted motions, $\beta = 165°$, Fn=0.12

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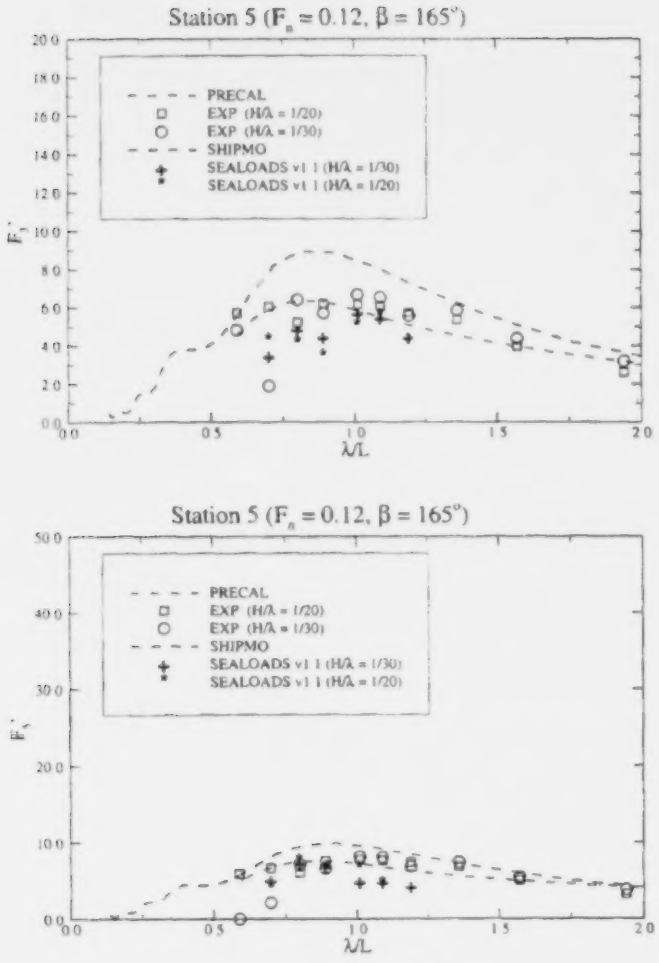

Figure 3.11: Predicted sea loads on station 5, $\beta = 165°$, Fn=0.12

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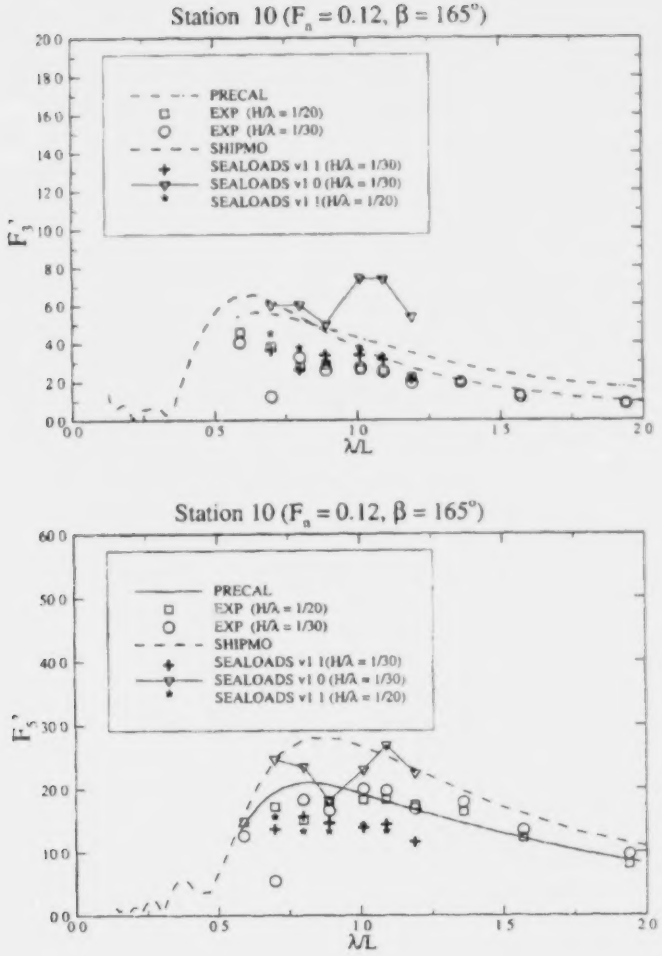

Figure 3.12: Predicted sea loads on station 10, $\beta = 165°$, Fn=0.12

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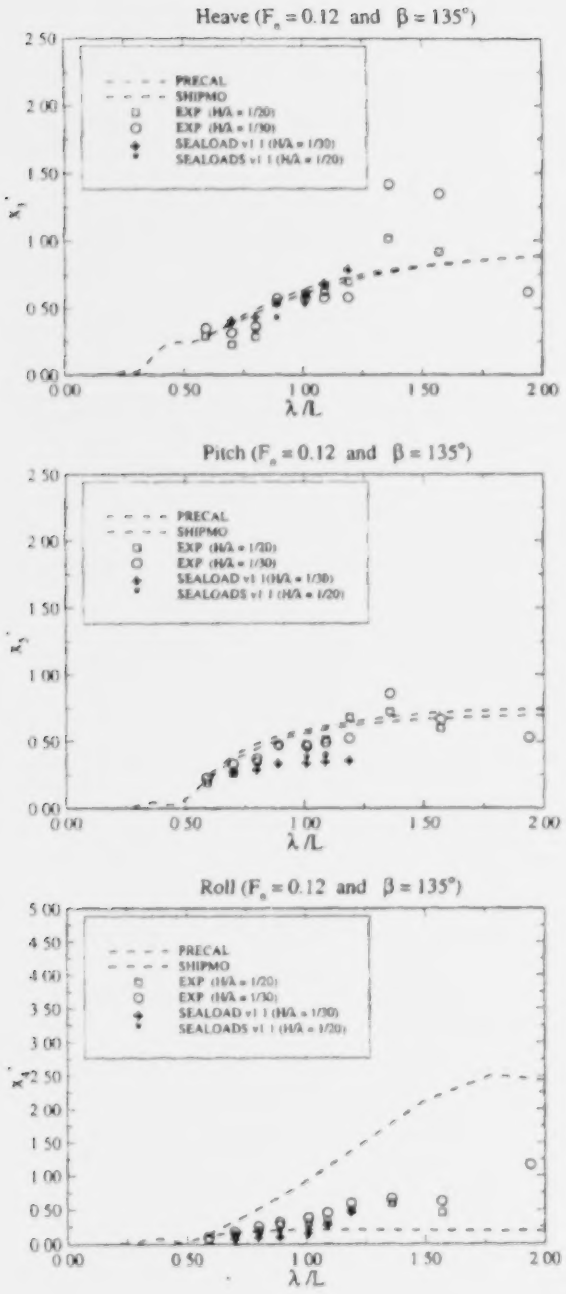

Figure 3.13: Predicted motions, $\beta = 135°$, Fn=0.12

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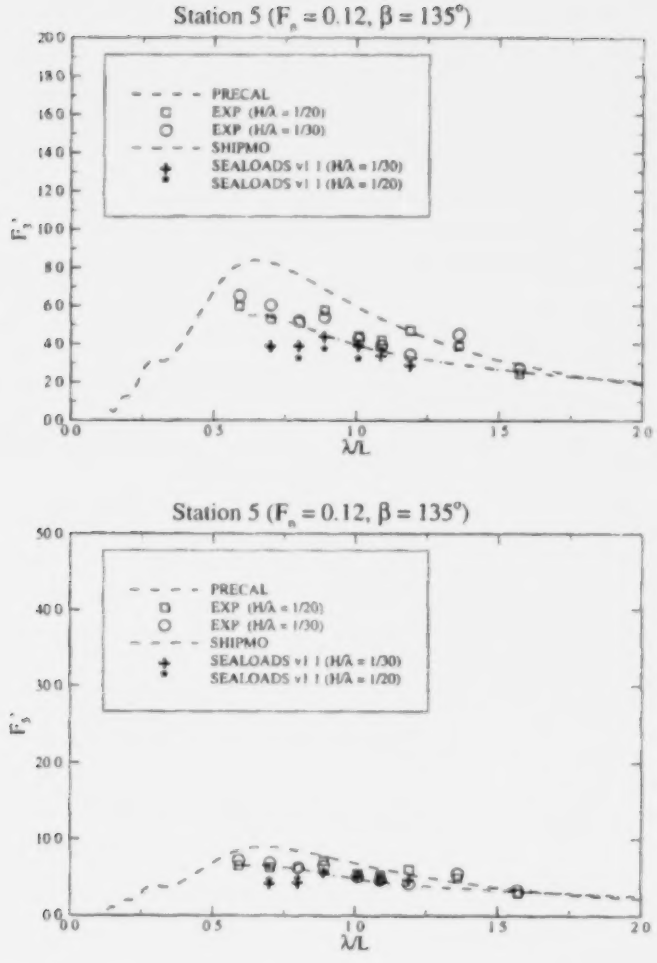

Figure 3.14: Predicted sea loads on station 5, $\beta = 135°$, Fn=0.12

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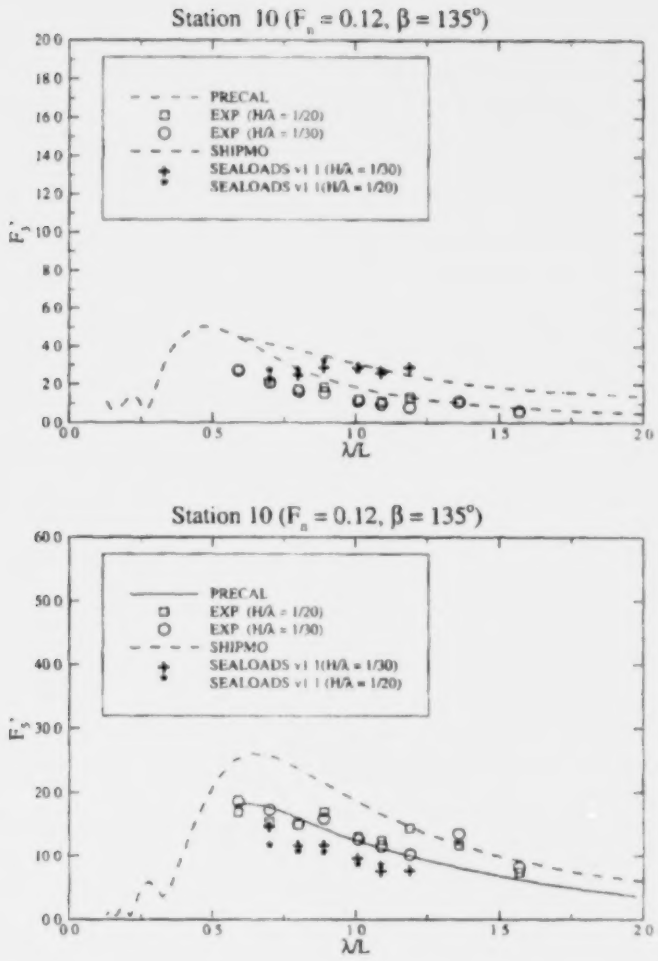

Figure 3.15: Predicted sea loads on station 10, $\beta = 135°$, Fn=0.12

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Table 3.4: TFE's of motions, sea loads and pressure predictions based on experimental data and ITTC spectrum (Fn=0.12 and $\beta = 180°$)

x's, F's	SEALOADS v1.0		SEALOADS v1.1		SHIPMO7		PRECAL	
and p's	SS5	SS6	SS5	SS6	SS5	SS6	SS5	SS6
x'_3	26.4	31.2	29.6	34.8	14.2	15.5	15.1	15.4
x'_5	11.4	13.2	11.7	13.0	5.9	5.5	11.3	11.6
$(F'_3)_5$	-	-	25.1	24.0	32.8	33.8	8.9	11.4
$(F'_3)_{10}$	189.9	226.7	49.8	73.3	48.1	44.0	65.1	67.3
$(F'_3)_{13.7}$	-	-	25.5	32.7	11.5	10.6	19.8	20.7
$(F'_5)_5$	-	-	32.7	36.4	25.6	27.9	10.4	14.9
$(F'_5)_{10}$	49.5	66.2	23.8	24.9	36.3	36.4	6.0	6.7
$(F'_5)_{13.7}$	-	-	24.3	25.0	48.6	47.6	19.6	20.3
$(p')_4$	-	-	51.5	54.0	-	-	27.6	25.3
$(p')_5$	-	-	28.2	24.4	-	-	53.4	51.2
$(p')_6$	-	-	63.9	80.2	-	-	32.4	29.8
$(p')_7$	-	-	47.5	49.2	-	-	22.3	20.7
$(p')_8$	-	-	584.4	663.7	-	-	431.1	499.2
$(p')_9$	-	-	99.0	115.8	-	-	127.1	153.4
$(p')_{10}$	-	-	58.6	70.4	-	-	198.7	238.1

Table 3.5: TFE's of motions, sea loads and pressure predictions based on experimental data and JONSWAP spectrum (Fn=0.12 and $\beta = 180°$)

x's, F's	SEALOADS v1.0		SEALOADS v1.1		SHIPMO7		PRECAL	
and p's	SS5	SS6	SS5	SS6	SS5	SS6	SS5	SS6
x'_3	32.3	34.2	35.7	36.9	15.8	16.1	15.6	15.8
x'_5	13.2	13.5	13.3	13.6	5.4	5.2	11.6	11.7
$(F'_3)_5$	-	-	23.9	23.9	34.2	34.9	12.1	13.2
$(F'_3)_{10}$	236.8	252.4	79.8	89.8	42.9	41.4	67.8	68.5
$(F'_5)_5$	-	-	38.0	40.7	28.7	30.1	16.2	18.2
$(F'_5)_{10}$	70.8	77.8	25.5	26.5	36.6	36.9	7.0	7.5
$(p')_4$	-	-	54.6	55.6	-	-	24.9	24.2
$(p')_5$	-	-	23.8	23.0	-	-	50.7	49.9
$(p')_6$	-	-	83.8	88.8	-	-	29.3	28.5
$(p')_7$	-	-	49.6	50.2	-	-	20.4	20.1
$(p')_8$	-	-	679.7	701.6	-	-	513.5	533.2
$(p')_9$	-	-	119.4	124.5	-	-	159.1	167.2
$(p')_{10}$	-	-	73.2	77.2	-	-	246.5	258.2

Table 3.6: TFE's of motions and sea loads based on experimental data and ITTC spectrum (Fn=0.12 and $\beta = 165°$)

x's and F's	SEALOADS v1.0		SEALOADS v1.1		SHIPMO7		PRECAL	
	SS5	SS6	SS5	SS6	SS5	SS6	SS5	SS6
x'_3	28.3	22.2	25.8	23.7	21.2	23.7	20.9	23.2
x'_4	48.0	47.7	30.4	29.7	163.1	160.5	78.6	82.2
x'_5	9.8	9.2	26.7	27.4	10.2	10.4	11.2	9.7
$(F'_3)_5$	-	-	20.6	19.8	25.3	22.9	14.3	14.6
$(F'_3)_{10}$	160.5	162.9	43.9	40.5	42.7	38.0	61.4	64.2
$(F'_5)_5$	-	-	35.0	35.1	18.0	16.0	15.1	15.5
$(F'_5)_{10}$	46.7	42.8	28.9	28.2	32.6	32.6	11.5	11.9

Table 3.7: TFE's of motions and sea loads based on experimental data and ITTC spectrum (Fn=0.12 and $\beta = 135°$)

x's and F's	SEALOADS v1.1		SHIPMO7		PRECAL	
	SS5	SS6	SS5	SS6	SS5	SS6
x'_3	23.3	24.5	38.1	39.3	38.2	39.2
x'_4	36.5	34.4	211.3	206.4	69.9	76.2
x'_5	25.7	26.2	20.9	21.6	22.9	24.1
$(F'_3)_5$	20.4	19.2	34.4	31.6	18.0	21.4
$(F'_3)_{10}$	120.2	132.9	57.9	52.1	155.5	159.4
$(F'_5)_5$	20.7	19.6	29.2	27.7	18.1	22.1
$(F'_5)_{10}$	22.1	22.6	41.5	37.9	20.5	23.3

Chapter 4

Conclusions and Recommendations

The mathematical model and the code of SEALOADS were examined specifically to identify the ways to improve the prediction of sea loads. A validation study was carried out only for cases of CPF at Fn=0.12. Compared with SEALOADS version 1.0, the prediction of sea loads was improved. The new version, SEALOADS version 1.1, includes the following new features:

- A module to generate variable hydrodynamic coefficients was introduced to model the instantaneous wetted surface. Improvement in ship motion simulation that have been demonstrated are extremely encouraging.
- New Green function tables have been provided to allow SEALOADS to accept arbitrary panels.
- Users have been provided with more flexibility and control over the operation of the software.

Based on the current work, the following recommendations are made for future work:

- Extensive validation needs to be carry out to further validate the module on variable hydrodynamic coefficients.
- The pressure computation is currently based on mean wetted surface. It should be extended to consider all points on the instantaneous wetted surface.
- A hydrostatic balancing module could be incorporated into the current code for further improvement of predictions
- Stokes waves could be used for computation of ship responses in steep large waves to examine the nonlinearity in responses.
- Maneuvering and rudder forces are important to numerical damping. Empirical models for these forces should be further investigated, particularly for different ships.
- Further validation work should be carried out for other naval ships.

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References

Ando, S. (1998). Quantification of Correlation of Predicted and Measured Transfer Functions for Ship Motions and Wave Loads. RINA International Conference on Ship Motions and Maneuverability, London, Paper No. 6.

Qiu, W., Peng, H. and Hsiung, C.C. (2001). Theoretical Manual for SEALOADS version 1.1 - a Computer Program for Prediction of Nonlinear Ship Motions, Sea Loads and Pressure Distribution in the Time Domain. Martec Limited, Halifax, Nova Scotia, Canada.

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Enhancement for the computer code SEALOADS version 1.0 was carried out and a new version 1.1 was produced. The mathematical model and the codes of SEALOADS version 1.0 were carefully examined for ways to improve the prediction of sea loads. A new algorithm has been developed to account for the effect of variable added-mass, damping and restoring coefficients on ship motions. A validation study for version 1.1 was conducted for the case of a frigate at the Froude number 0.12. Results were compared with those from PRECAL and SHIPMO7 as well as the experimental data. A total-factor-error analysis was also carried out using two wave spectra - ITTC and JONSWAP. The computed results show an improvement in the sea loads prediction.

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